**UNITED STATES ENVIRONMENTAL PROTECTION AGENCY**
**WASHINGTON D.C. 20460**

March 14, 2001

**OFFICE OF**
**THE ADMINISTRATOR**
**SCIENCE ADVISORY BOARD**

Note to the Reader:

The attached draft report is a draft report of the Science Advisory Board (SAB). The draft is still undergoing final internal SAB review, however, in its present form, it represents the consensus position of the panel involved in the review. Once approved as final, the report will be transmitted to the EPA Administrator and will become available to the interested public as a final report.

This draft has been released for general information to members of the interested public and to EPA staff. This is consistent with the SAB policy of releasing draft materials only when the Committee involved is comfortable that the document is sufficiently complete to provide useful information to the reader. The reader should remember that this is an unapproved working draft and that the document should not be used to represent official EPA or SAB views or advice. Draft documents at this stage of the process often undergo significant revisions before the final version is approved and published.

The SAB is not soliciting comments on the advice contained herein. However, as a courtesy to the EPA Program Office which is the subject of the SAB review, we have asked them to respond to the issues listed below. Consistent with SAB policy on this matter, the SAB is not obligated to address any responses which it receives.

1. Has the Committee adequately responded to the questions posed in the Charge?
2. Are any statements or responses made in the draft unclear?
3. Are there any technical errors?

For further information or to respond to the questions above, please contact:

Sam Rondberg, Designated Federal Officer
Science Advisory Board (1400A)
US Environmental Protection Agency
1200 Pennsylvania Avenue, NW
Washington, DC 20460
(301) 812-2560 Fax: (410) 286-2689
E-Mail: samuelr717@aol.com

# RADIATION IN SEWAGE SLUDGE: INTERAGENCY STEERING COMMITTEE ON RADIATION STANDARDS (ISCORS) DOSE MODELING REPORT -- AN SAB REPORT

**BY THE RADIONUCLIDES IN SEWAGE SLUDGE SUBCOMMITTEE OF THE RADIATION ADVISORY COMMITTEE**

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**EXECUTIVE COMMITTEE REVIEW DRAFT
3/13/2001**

**FOR REVIEW ONLY – DO NOT QUOTE OR CITE**

**March 13, 2001 Draft**

EPA-SAB-ADV-01-0XX

The Honorable Christine Todd Whitman
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, NW
Ariel Rios Building, Mail Code 1100
Washington, DC 20460

Re: Radiation in Sewage Sludge: Interagency Steering Committee on Radiation Standards (ISCORS) Dose Modeling Report -- An SAB Report

Dear Governor Whitman:

The enclosed report was developed by the Radionuclides in Sewage Sludge Subcommittee (RSSS) of the Radiation Advisory Committee (RAC) of the Science Advisory Board (SAB) in response to a request from the Office of Radiation and Indoor Air (ORIA) to review technical aspects of the *Radionuclides in Sewage Sludge: Dose Assessment, Dose Modeling Report* that was developed by the Interagency Steering Committee on Radiation Standards (ISCORS) Sewage Sludge Subcommittee (SSS).

The RSSS held a public meeting in Washington, DC on December 12, 13, and 14, 2000, at which it was briefed by, and had technical discussions with, the members of the ISCORS SSS, Dose Modeling Workgroup and received comments from members of the public. Additional writing/editing sessions were held by teleconference.

The enclosed report is organized around three primary Charge questions, and, in addition, provides some further advice to the Agency concerning several issues beyond the Charge.

The first element of the Charge asked if the overall dose modeling methodology, including model selection, is adequate. The RSSS accepts the ISCORS SSS decision to address radiation exposure from sewage sludge and ash with RESRAD (this model, as with many others referred to in this report, is denoted by an assigned name rather than an abbreviation or acronym), a model that is readily available, widely used, and employs a probabilistic approach for quantifying both dose,and the uncertainty associated with the dose modeling results. The RSSS also supports strongly the use of other radiation dose models (e.g., PRESTO, GENII, and MICROSHIELD) to benchmark RESRAD as it is used for sewage sludge dose modeling. We also encourages the ISCORS SSS to verify and document the capability of the RESRAD family of codes to employ probabilistic input parameter values for the various exposure scenarios.

The RSSS also accepts the ISCORS SSS proposal to characterize the impact of radionuclides in sewage sludge in terms of “total effective dose equivalent” (TEDE) rather than attempting to go directly from radionuclide intake and direct radiation exposure to “risk.” In this particular application, TEDE is appropriate for use in comparing the modeling results with existing standards and background values. The dose calculations were based on dose conversion factors given in Federal Guidance Report 11 (FGR-11) that were derived using the 1977 International Commission on Radiological Protection (ICRP) approach. Revised ICRP dose coefficients for members of the public that incorporate age differences have since been published and the RAC recommends that ICRP 72 (ICRP 1996) be used or that the influence of age on dose, especially as received by infants and children, be considered in the assessment.

The second Charge question asked if the dose modeling scenarios were reasonable, if they are they sufficiently representative of the major exposure situations, and if the document adequately explains them. The RSSS commends the ISCORS SSS for its identification and description of a range of plausible radiation exposure scenarios affecting both workers and members of the general public. Although each of these scenarios is reasonable, potentially critcal exposure pathways have not been fully examined. Onsite and landfill exposure scenarios failed to completely account for important site-specific heterogeneities such as fracture flow that could result in rapid and long-range transport of radionuclides. The RSSS recommends that the SSS consider the possibility of both soluble and colloidal transport of radionuclides associated with runoff from fields receiving sewage sludge applications. The SSS should evaluate the impact of the POTW sludge dewatering operations on the transport and bioavailability of radionuclides in land-applied sewage sludge. Although the RAC recognizes that the SSS dose modeling effort was restricted to sewage sludge *per se*, the final document should also discuss the potentially important contributions to dose of liquid effluents, either from discharge to waters used for drinking water or from use for irrigation.

The RSSS urges the ISCORS SSS to explicitly incorporate the 40 CFR Part 503 guidelines (and other applicable requirements) that limit the design and operation of sewage sludge land application, incineration, and surface disposal sites into the exposure scenarios. The RAC also encourages the SSS to incorporate existing and validated methodologies for determining reasonable parameter values and recommends full characterization of the sludge and ash to include analysis for all radionuclides of concern.

The last Charge question addressed the the approaches to obtaining modeling parameters and distributions, asking if they were scientifically defensible, and if the methodology's approach for characterizing uncertainty was appropriate. The RSSS found that the description of the sensitivity and uncertainty analysis in the current draft is inadequate for judging whether or not it is appropriate. The SSS should provide better documentation for the selection of parameters and their distributions.

The RSSS identified several additional issues calling for comment. The Subcommittee noted that the SSS considered only the radiation exposure from sewage sludge, raising the possibility of underestimating the doses received by persons coming into contact with both the sludge and associated effluent. The radionuclides contained in the liquid effluent from the POTW may contribute to the total dose experienced by people living near or working at POTWs. Additionally, liquid effluent can be used for irrigation of sites to which sludge has been applied, resulting in concentrations of radionuclides in soils higher than the assumed values in the source term for RESRAD. At a minimum, these issues should be discussed in the final dose assessment document.

Also, the RSSS understands the EPA is considering revision of FGR-11 to reflect ICRP Publication 72 values. If the revised FGR-11 becomes available in time for incorporation into this Sewage Sludge Dose Modeling report, it would be desirable to do so, both because of the improved dosimetry models used and the added ability to consider intakes by subjects of different ages.

The RSSS appreciates the opportunity to provide this report to you and to the ISCORS SSS and we hope that it will be helpful. We look forward to the response of the Assistant Administrator for Air and Radiation to the our comments and recommendations.

Sincerely,

Dr. William Glaze, Chair
Science Advisory Board

Dr. Janet Johnson, Chair
Radiation Advisory Committee
Science Advisory Board

Dr. Jill Lipoti, Chair
Radionuclides in Sewage Sludge Subcommittee
Radiation Advisory Committee
Science Advisory Board

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# ABSTRACT

On December 12-14, 2000, the Radionuclides in Sewage Sludge Subcommittee (RSSS) of the Radiation Advisory Committee (RAC) reviewed the dose modeling report of the Interagency Steering Committee on Radiation Standards, Sewage Sludge Subcommittee (ISSS). This included advice on dose modeling methodology, model selection, scenarios, approaches to obtaining modeling parameters and distributions, and approaches for uncertainty.

The RSSS accepted the ISSS's decision to use the model RESRAD, but supported the use of other radiation dose models for bench marking RESRAD's application to sewage sludge dose modeling. The RSSS also accepted ISSS's use of radiation dose quantities, rather than risk, to express the impact of radionuclides in sewage sludge. The RSSS recommended that the revised dose coefficients published in ICRP 72 be used if feasible or, at a minimum, the possible effects of age on dose be considered. While commending the ISSS for identifying a range of plausible radiation exposure scenarios, the RSSS identified several exposure pathways that were not considered and recommended that regulatory requirements concerning sludge disposition be integrated into the modeling effort to prevent use of unrealistic scenarios or parameters. The RSSS recommended that the selection of parameters and their distributions, as well as the sensitivity and uncertainty analyses, be better described and that a two-dimensional uncertainty analysis, addressing both variability and uncertainty, be considered. The RSSS made recommendations beyond the charge to consider exposure to liquid effluent from POTWs, and to use SI units. The RSSS made a general recommendation to update FGR-11 to reflect values in ICRP Publication 72.

**KEY WORDS**: sewage sludge, ash, dose modeling, RESRAD, dose coefficients, effects of age on dose, radiation exposure scenarios for the POTW worker, radiation exposure scenarios for the general public, critical exposure pathways, land application of sewage sludge, land reclamation with sewage sludge, bioavailability of radionuclides in sewage sludge, solubility of radionuclides in sewage sludge, model validation

# U.S. ENVIRONMENTAL PROTECTION AGENCY
# SCIENCE ADVISORY BOARD
# RADIONUCLIDES IN SEWAGE SLUDGE SUBCOMMITTEE
# OF THE RADIATION ADVISORY COMMITTEE

**December 12-14, 2000 Meeting**

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**Dr. Genevieve S. Roessler,** Radiation Consultant, Elysian, MN

**CONSULTANTS**

**Dr. Vicki M. Bier**, University of Wisconsin, Madison, WI[1]

**Dr. Stephen L. Brown,** R2C2 Risks of Radiation & Chemical Compounds, Oakland, CA

**Dr. Michael J. McFarland**, Dept. of Civil and Environmental Engineering, Utah State University, Logan, UT

**Dr. Bobby R. Scott**, Lovelace Respiratory Research Institute, Albuquerque, NM[2]

**SCIENCE ADVISORY BOARD STAFF**

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2 Did not attend meeting of December 12-14, 2000, but participated in the review

**Ms. Melanie Medina-Metzger**, Designated Federal Officer, US EPA Science Advisory Board (1400A), US EPA, 1200 Pennsylvania Avenue, NW, Washington, DC 20460

**Mr. Samuel Rondberg**, Designated Federal Officer, US EPA Science Advisory Board (1400A), US EPA, 1200 Pennsylvania Avenue, NW, Washington, DC 20460

**Ms. Diana L. Pozun**, Management Assistant, US EPA Science Advisory Board (1400A), US EPA, 1200 Pennsylvania Avenue, NW, Washington, DC 20460

**Ms. Dorothy Clark**, Management Assistant, US EPA Science Advisory Board (1400A), US EPA, 1200 Pennsylvania Avenue, NW, Washington, DC 20460

# TABLE OF CONTENTS

# 1. EXECUTIVE SUMMARY

The Office of Radiation and Indoor Air (ORIA), in cooperation with other Federal agencies comprising the Sewage Sludge Subcommittee (SSS) of the Interagency Steering Committee on Radiation Standards (ISCORS), is developing guidance to inform Publicly Owned Treatment Works (POTW) authorities of the possibility for radioactive materials to concentrate in sewage sludge and incinerator ash. A second purpose is to help the POTW authorities determine what actions may be considered depending on the concentration of radioactive materials present in their sewage sludge or ash. As part of the effort by the SSS, a report on dose modeling for radionuclides in sewage sludge and ash was prepared. The Radiation Advisory Committee (RAC) was asked to review the dose modeling report and formed the Radionuclides in Sewage Sludge Subcommittee (RSSS) to undertake this task.

The following report is organized around three primary Charge questions (see section 2.2 for the detailed Charge), and, in addition, provides some further advice to the Agency concerning several issues beyond the Charge.

The first element of the Charge asked if the overall dose modeling methodology, including model selection, is adequate. The RSSS accepts the ISCORS SSS decision to address radiation exposure from sewage sludge and ash with RESRAD, a model that is readily available, widely used, and according to information supplied to the Subcommittee, has been modified to allow the use of a probabilistic approach for quantifying dose, as well as the uncertainty associated with the dose modeling results. However, to achieve greater transparency, the RSSS recommends that a discussion of the conceptual framework for the model be presented in terms of the possible applications envisioned by ISCORS for the dose modeling effort.

The RSSS strongly supports the use of other radiation dose models (e.g., PRESTO, GENII, and MICROSHIELD) for bench marking RESRAD. Any validation of the RESRAD model for which appropriate data are available, specific to its use in sewage sludge dose assessment, would enhance the credibility of the predicted values. The RSSS also encourages the ISCORS SSS to verify and document the capability of the RESRAD family of codes to employ probabilistic input parameter values for the various exposure scenarios. Finally, the RSSS recommends that the ISCORS SSS explore options for including model modifications to the RESRAD family of codes that will be necessary to faithfully capture some important site-specific characteristics.

The RSSS accepts the ISCORS SSS proposal to characterize the impact of radionuclides in sewage sludge in terms of "dose." In this particular application, "dose" is appropriate for use in comparing the results with existing standards and background values. However, the ISCORS SSS is cautioned about the use of the "dose" terminology and a glossary of appropriate dose terms is provided.

The RSSS was informed by members of the ISCORS SSS that "dose" as used in its dose assessment document means "Total Effective Dose Equivalent." The dose calculations were based on dose conversion factors given in Federal Guidance Report (FGR) 11. The values in FGR-11 were based in the ICRP approach defined for adult workers in ICRP Publications 26 (ICRP 1976) and 30 (ICRP 1977-1988). Revised ICRP dose coefficients for members of the public for ingestion and inhalation have been published and the RSSS recommends that ICRP Publication 72 (ICRP 1996) and the associated CD-ROM published in ICRP 1998 be used. Even if the ICRP Publication 72 approaches cannot be used in this report, it is important that the possible effects of age on dose, especially as received by infants and children, be considered in the assessment.

The ISCORS SSS should clarify the specific circumstances for which the total effective dose equivalent values are being calculated. The impact of possible changes in exposure conditions from year to year should be included in the uncertainty analyses.

The ISCORS SSS has estimated the source term for many of the scenarios by assuming that 100 years of sludge application is mixed with the surface layer of soil. That procedure will overestimate the actual concentration because of losses during the period of application. The losses would occur not only from radioactive decay, but from erosion by wind and precipitation, by leaching to the groundwater, and by uptake and removal with crops. A better approach is to apply an effective half-life derived for the removal processes using radioactive decay constants, the universal soil-loss equation, and loss rates consistent with the assumptions about movement to groundwater and uptake in plants.

The second Charge question asked if the dose modeling scenarios were reasonable, if they are they sufficiently representative of the major exposure situations, and if the document adequately explains them? The ISCORS SSS is commended for its identification and description of a range of plausible radiation exposure scenarios affecting both the POTW workers as well as the general public. The exposure scenarios included a) nearby towns, b) onsite residents, c) landfill neighbors, d) incineration neighbors, e) recreational area use, f) agricultural application workers, g) low-exposure POTW workers (belt filter press operators) and h) high- exposure POTW workers (bagging of dewatered sludge).

Although each of these scenarios is reasonable, the ISCORS SSS has not fully examined potentially critical exposure pathways in some cases. Onsite and landfill exposure scenarios failed to completely account for important site-specific heterogeneities such as fracture flow that could result in rapid and long-range transport of radionuclides. The scenario descriptions do not mention the possibility of both soluble and colloidal transport of radionuclides associated with runoff from fields receiving sewage sludge applications. Additionally, as stated in Section 3.4, (Issues Beyond the Charge), the discharge of aqueous effluent from the POTW is not considered. A critical omission in the ISCORS SSS dose modeling report is an evaluation of the impact of the POTW sludge dewatering operations on the transport and bioavailability of radionuclides in land -applied sewage sludge.

In general, the dose modeling report adequately captures the major exposure situations affecting the general public. The RSSS endorses the ISCORS SSS development and implementation of a transparent screening process that permits the relative ranking of exposure scenarios, which is critical for determining for which scenarios further refinement is justified. The RSSS encourages the development of a similar transparent screening tool for objectively identifying POTW worker situations which represent major sources of radiation exposures. The RSSS recommends that the ISCORS SSS explore methods for obtaining appropriate data to better characterize the distribution of exposure durations for typical land application operations and to critically evaluate and appropriately document its assumptions.

Although the radiation exposure scenarios described in the dose modeling report are appropriate for capturing the range of likely opportunities for radiation exposure from sewage sludge, it is not clear that the scenarios incorporated the specific regulatory requirements that currently limit how sludge may be used or disposed. The RSSS encourages the ISCORS SSS to explicitly incorporate the 40 CFR Part 503 guidelines (and other applicable requirements) that limit the design and operation of sewage sludge land application, incineration, and surface disposal sites. The RSSS also encourages the ISCORS SSS to incorporate existing and validated methodologies for defining reasonable parameter values.

In many land reclamation projects, the quantity of land-applied sludge is considerably greater than what is allowable under the agricultural production scenario. Under these circumstances, the extent of soil mixing is generally minimal, particularly at those land reclamation sites which contain little or no topsoil. The RSSS recommends that the ISCORS SSS provide scientific justification for assigning specific dilution factors to the source terms.

The RSSS recommends full characterization of the sludge and ash to include analysis for all radionuclides of concern. Further, all radionuclides that are identified through the analysis of the sludge and ash should be included in the radionuclide libraries of the models. It appears that a potentially important radionuclide ($^{99m}Tc$ ) was omitted.

The last Charge question addressed the the approaches to obtaining modeling parameters and distributions, asking if they were scientifically defensible, and if the methodology's approach for characterizing uncertainty was appropriate. In general, the selection of parameters and their distributions was not well described in the ISCORS SSS draft dose modeling report provided to the

RSSS. However, in the oral presentations, the Subcommittee members indicated that future drafts would be much improved and the RSSS supports such improvements.

The use of one $K_d$ for each radionuclide without consideration of speciation and other factors that cause $K_d$s, solubilities, and bioavailabilities to vary across POTWs and land applications is not appropriate. This could be handled by assigning these parameter values by species and application scenario or by widening the variability distributions for each radionuclide, as well as including an additional degree of uncertainty. The RSSS recommends that outside advice be obtained on how to treat the mobility of radionuclides in a soil-sludge mixture.

The description of the sensitivity and uncertainty analysis in the current draft is inadequate for judging whether or not it is appropriate. A more informative uncertainty analysis would be two-dimensional, addressing both variability and uncertainty, and would examine not only parameter uncertainty, but also uncertainties introduced by the selection of models and assumptions. ISCORS SSS should, at a minimum, acknowledge the difference between variability and uncertainty and provide an indication for each source, whether the distributions reflect variability, uncertainty, or a combination of both. The Subcommittee should address other sources of variability and uncertainty, such as dose conversion factors (including particle size distributions). The uncertainty analysis should recognize correlations among parameters.

A full description of the particular Latin Hypercube method employed should be provided and the number(s) of realizations for the Monte Carlo runs should be justified.

In the sensitivity analysis, the statements regarding non-linearity should have some technical or physical basis.

Finally, the RSSS identified, and commented on, some issues not delineated in the Charge. The RSSS understands that the ISCORS SSS is limited to assessing doses from disposition of sewage sludge *per se* and did not intend to assess doses from discharges of liquid effluents from POTWs to nearby waters. However, the fraction of soluble radioactive material contained in the liquid effluent from the POTW may, under some site-specific conditions, contribute significantly to the total dose experienced by people living near or working at POTWs. Additionally, liquid effluent can be used for irrigation of sites to which sludge has been applied, rather than water form other sources. Therefore concentrations of radionuclides in soils may be higher than assumed in the source term for RESRAD and there may be additional occupational routes of exposure or an additional airborne source term. At a minimum, these issues should be discussed in the final dose assessment document.

The RSSS understands that the ISCORS SSS is under a time constraint to provide the dose model as a tool to help interpret the results from the analysis of sludge and ash from 300 POTWs nationwide. These results will be available in a few months and it is important to assist POTWs with assessment. The EPA is considering revision of FGR-11 to reflect ICRP Publication 72 values. If the revised FGR-11 were available in time for incorporation into this Sewage Sludge Dose Modeling report, it would be desirable to do so, both because of the improved dosimetry models used and the added ability to consider intakes by subjects of different ages.

Conventional units are used throughout the document. The RSSS recommends the use of SI units. The RSSS has also provided a glossary of terms which the ISCORS SSS should use to clarify the document. The RSSS further recommends that Appendix A be revised to provide more complete information in a more consistent manner for all radionuclides of interest, and that Appendix B be modified or eliminated.

# 2. INTRODUCTION

## 2.1 Background

During the process of treating sewage, radionuclides can become reconcentrated in the residual solids, known as sewage sludge. The radionuclides can come from discharges of man-made radioactive material by licensed users or from naturally occurring radioactive materials. In a 1994 report, the General Accounting Office (GAO) **(Will supply full citation)** described nine cases where contamination found in sewage sludge or ash or the wastewater collection system resulted in considerable cleanup expense to the POTW authority or the specific industrial discharger of the wastewater. These incidents have been investigated and documented, but these investigations did not indicate the prevalence of radionuclides in POTW sludge and ash around the country. These incidents also do not indicate whether levels actually measured pose a threat to human health and the environment.

This review was carried out in response to a request from EPA's Office of Radiation and Indoor Air (ORIA). The ORIA requested that the RAC review technical aspects of the *Radionuclides in Sewage Sludge*: *Dose Assessment*, *Dose Modeling Report*, that was developed by the Sewage Sludge Subcommittee (SSS) of the Interagency Steering Committee for Radiation Standards (ISCORS). The SSS of the ISCORS comprises representatives from the EPA, NRC, Department of Energy, Department of Defense, State of New Jersey, City of Cleveland, and the county of Middlesex, New Jersey.

The RAC formed the Radionuclides in Sewage Sludge Subcommittee (RSSS) to conduct the review. The RSSS met in Washington, DC on December 12-14, 2000, and was briefed by members of the ISCORS Sewage Sludge Subcommittee's Dose Assessment Workgroup. In addition, the RSSS conducted a publically noticed teleconference on November 27, 2000, and two writing/editing sessions by teleconference on December 21, 2000, and January 5, 2001.

### 2.2 Charge to the SAB

The draft *Sewage Sludge Dose Modeling Report* provided the methodology for the concerned agencies to use to assess potential radiation doses to workers and the public from various sewage sludge handling and disposal practices. The dose estimates would then be included in the final Guidance Document to help operators of POTW understand and interpret radionuclide data associated with sewage sludge and ash analyses. The Charge questions were:

a) Is the overall dose modeling methodology, including model selection, adequate?

b) Are the dose modeling scenarios reasonable? Are they sufficiently representative of the major exposure situations? Does the document adequately explain them?

c) Are the approaches to obtaining modeling parameters and distributions scientifically defensible? Is the methodology's approach for characterizing uncertainty appropriate?

# 3. DETAILED FINDINGS AND RECOMMENDATIONS

## 3.1 Dose Modeling Methodology, Including Model Selection

### 3.1.1. Model Selection

The RSSS accepts the ISCORS SSS decision to address radiation exposure from sewage sludge and ash with RESRAD, a model that is readily available, widely used, and, according to information supplied to the Subcommittee, has been modified to allow the use of a probabilistic approach for quantifying dose, as well as the uncertainty associated with the dose modeling results. The RESRAD family of codes has considerable flexibility in allowing the user to input site-specific values and evaluating the potential dose to an on-site personnel.

To achieve greater transparency, the RSSS recommends that a discussion of the conceptual framework for the model be presented in terms of the possible applications envisioned by ISCORS for this dose modeling effort. Although the basic framework, in which the dose assessment methodology has been developed, is fundamentally sound, the descriptions of many of the principal components of the process are inadequate. In particular, the ISCORS report section on "Model Selection" (i.e., Chapter 4) is incomplete and preliminary at this time, although the RSSS understands that the limitations of the RESRAD family of codes will be identified along with their consequences on dose calculations. Given that RESRAD is the model of choice, Chapter 4 of the dose modeling report should be restructured to provide adequate information to support this choice.

The current Table 4.1 indicates that several pathways are not included by RESRAD 5.95 and the RSSS is not certain whether they are addressed by RESRAD 6.0. These pathways are a) ingestion of drinking water from a contaminated river, b) ingestion of fish, and c) surface water run-off. These pathways should be included.

The RSSS strongly supports the use of other radiation dose models (e.g, PRESTO, GENII, and MICROSHIELD) for bench marking RESRAD in its specific use in the sewage sludge dose modeling. Bench marking may be particularly useful with respect to the inclusion of CAP-88 as the air dispersion model for RESRAD-Offsite. Moreover, any validation of RESRAD specific to its use in sewage sludge dose assessment would enhance the credibility of its predictions. For example, concentrations of radionuclides in soil at a known old sewage sludge application site could be compared with the radionuclide concentration assumptions of RESRAD if the history of sludge application, including concentration data for the applied sludge, was available. Validation of any other modules of RESRAD for which appropriate data are available would also enhance the credibility of its predicted values.

Supporting quality control/quality assurance documentation for RESRAD was not made available to the RSSS, leading to a concern that there could be a problem in using RESRAD for the implementation of the probabilistic assessment of dose. It is unclear whether RESRAD was, in fact, developed with the expectation that probabilistic methods would eventually be employed for assigning input parameter values. If the model was initially developed without consideration of its possible use for probabilistic analysis, the inclusion of “probabilistic distributions” rather than “deterministic” values could lead to extrapolations beyond the range of applicability of the model. Secondly, the use of a probabilistic approach for assigning input values to a deterministic model can result in a singularity in the model, caused by a division by zero or some other nonphysical result. Although future documentation of the models may resolve these concerns, the RSSS encourages the ISCORS SSS to verify and document the capability of the RESRAD family of codes to employ probabilistic input parameter values for the various exposure scenarios.

Finally, the RSSS recommends that the ISCORS SSS explore options for including model modifications to the RESRAD family of codes that will be necessary to faithfully capture some important site-specific characteristics. For instance, fracture vs. matrix groundwater flow, indoor contamination and near-field air dispersion characteristics, dose coefficients, exposure factors, and other age dependence factors should be captured by RESRAD as it is used in this application.

### 3.1.2. Dose Modeling Methodology

The RSSS accepts the ISCORS Subcommittee proposal to characterize the impact of radionuclides in sewage sludge in terms of "dose." In this particular application, "dose" is appropriate for use in comparing the results with existing standards and background values. However, the choice of dose vs. risk and the decision to use Federal Guidance Report (FGR) 11 and 12, rather than FGR-13, should be explicitly discussed for clarity.

The ISCORS SSS should be careful in the use of "dose" terminology. The unmodified term "dose" is not defined in the conventional health physics literature and should be defined in the document in which it is used. Definitions of appropriate dose terms are provided in the glossary of this advisory.

The RSSS was informed by members of the ISCORS SSS that "dose," as used in its dose assessment document, means "Total Effective Dose Equivalent," but this should be clarified in the document. Apparently, the dose calculations are based on the Dose Conversion Factors given in FGR-11. The values in FGR-11 are, in turn, based on the ICRP approach defined for adult workers in ICRP Publications 26 (ICRP 1976) and 30 (ICRP 1977-1988).

Revised ICRP dose coefficients for members of the public for ingestion and inhalation have been published since the publication of FGR-11. These dose coefficients incorporate the tissue weighting factors given in ICRP Publication 60 (ICRP 1991) and a number of revised metabolic models described in ICRP Publications 56 (ICRP 1989), 67 (ICRP 1994), 69 (ICRP 1995a), and 71 (ICRP 1995b). Committed effective dose coefficients are computed for several different age groups (3 months, 1, 5, 10, and 15 years and adult). Results of these calculations for intakes of a broad range of radionuclides by ingestion or inhalation are given in ICRP Publication 72 (ICRP 1996) and the associated CD-ROM published in ICRP 1998. The ICRP Publication 72 dose coefficients are, in some cases, different by as much as an order of magnitude from the FGR-11 dose coefficients. The RSSS recommends that ICRP Publication 72 methods be used in place of FGR-11, if time permits.

Even if ICRP Publication 72 approaches cannot be used in this report, it is important that the possible effects of age on dose, especially as received by infants and children, be considered in the assessment. In some of the scenarios proposed by the ISCORS Sewage Sludge Subcommittee, exposures can continue over an entire lifetime. Perhaps simple bounding calculations could be performed for some important radionuclides that would indicate the relative importance of exposure in the childhood years compared with the annual intakes received as adults. Results of such analyses could be presented and discussed as part of the uncertainty analyses.

It is important that the ISCORS SSS clarify the specific circumstances for which the total effective dose equivalent values are being calculated. According to the text, a one-year exposure will be used along with a 50-year dose-commitment period. Because the exposure scenarios that have been selected involve exposures over many years, it is not clear from the draft report what exposure year will be used for these calculations. According to information supplied to the Subcommittee. RESRAD has the ability to calculate these dosimetry values for many years and report the highest annual value. The authors should elaborate on their strategy for selecting and using particular years in their calculations. The impact of possible changes in exposure conditions from year to year should be included in the uncertainty analyses.

The ISCORS SSS has estimated the source term for many of the scenarios by assuming that 100 years of sludge application is mixed with the surface layer of soil, resulting in a two-to-one dilution of the assumed 1 pCi/g concentration of a radionuclide in the sludge. That procedure will overestimate, often greatly, the actual concentration because of losses during the period of application. The losses would occur not only from radioactive decay, but from erosion by wind and precipitation, by leaching to the groundwater, and by uptake and removal with crops. A better approach is to apply an effective half-life derived for the removal processes using radioactive decay constants, the universal soil loss equation, and loss rates consistent with the assumptions about movement to groundwater and uptake in plants. Then a steady-state concentration in soil could be calculated for equilibrium conditions. (See the Foster Wheeler Environmental Corporation report prepared for the California Department of Food and Agriculture and the Heavy Metal Task Force (1998) for information on a modeling approach that includes erosion and other losses.)

### 3.2 Dose Modeling Scenarios

The ISCORS SSS is commended for its identification and description of a range of plausible sewage sludge exposure scenarios affecting both the POTW worker as well as the general public. The exposure scenarios included a) nearby town, b) onsite personnel, c) landfill neighbor, d) incineration neighbor, e) recreational area use, f) agricultural application worker, g) low exposure POTW worker (belt filter press operator), and h) high-exposure POTW worker (bagging of dewatered sludge).

Although these scenarios are reasonable, the ISCORS SSS has not fully examined potentially critical exposure pathways in some cases. The onsite and landfill exposure scenarios failed to completely account for important site-specific heterogeneities such as fracture flow that could result in rapid and long-range transport of radionuclides. The scenario descriptions do not mention the possibility of both soluble and colloidal transport of radionuclides associated with runoff from fields receiving sewage sludge applications. Additionally, as stated in Section 3.4 (Issues Beyond the Charge), the discharge of aqueous effluent from the POTW is not considered. The RSSS believes it is important that these transport mechanisms be included even if it means using a model other than RESRAD or modifying RESRAD.

A critical omission in the ISCORS SSS dose modeling report is an evaluation of the impact of the POTW sludge dewatering operations on the transport and bioavailability of radionuclides in land-applied sewage sludge. For example, while filtration and centrifugal dewatering processes (e.g., filter presses, centrifuges, etc.) effectively separate soluble radionuclides from the sludge solids, evaporative dewatering processes (e.g., drying beds) retain both insoluble and soluble radionuclides in the final sludge product. Because of the potential for some land-applied sewage sludge to contain a relatively large and highly mobile fraction of soluble radionuclides, dose modeling scenarios should clearly describe the impact of the type(s) of dewatering process operations used at the POTW on both the final sewage sludge quality and the predominant mechanisms that influence radionuclide transport in the environment. In addition to potentially enhancing the rate and extent of radionuclide transport, a larger fraction of soluble radionuclides in land-applied sewage sludge may also impact the biokinetic properties of radionuclides taken into the body and resulting dosimetry calculations. Simple mass balance calculations that reasonably reflect the fate and transport of radionuclides in land-applied sewage sludge can be used to document the relative importance of both radionuclide solubility and POTW sludge dewatering operations on estimated radiation dosages.

In general, the dose modeling report adequately captures the major exposure situations affecting the general public. The RSSS endorses the ISCORS Sewage Sludge Subcommittee's development and implementation of a transparent screening process that permits the relative ranking of exposure scenarios, which is critical for determining for which scenarios further refinement is justified. The RSSS encourages the ISCORS SSS to develop a similar transparent screening tool for objectively identifying POTW worker situations which represent major sources of radiation exposures. Without such a screening process, it is impossible to determine whether, in fact, the two POTW worker scenarios addressed in the report actually capture the full range of likely exposures. The RSSS recommends that the ISCORS SSS explore methods for obtaining appropriate data to better characterize the distribution of exposure durations for typical land-application operations. The RSSS expressed concern that the ISCORS SSS did not adequately justify assumptions for occupational exposures (e.g., 2000 hour annual exposure) given the seasonal nature of the land application activities in most parts of the country. The RSSS recommends that the ISCORS SSS critically evaluate and appropriately document its assumptions.

Although the radiation exposure scenarios described in the dose modeling report are appropriate for capturing the range of likely opportunities for radiation exposure from sewage sludge, it is not clear that the scenarios incorporated the specific regulatory requirements that currently limit how sludge may be used or disposed. The RSSS encourages the ISCORS SSS to explicitly incorporate the 40 CFR Part 503 guidelines (and other applicable requirements) that limit the design and operation of sewage sludge land-application, incineration, and surface disposal sites when selecting model parameters and distributions. Moreover, where appropriate, the RSSS encourages the ISCORS SSS to incorporate existing and validated methodologies for defining reasonable parameter values (e.g., use of the Hydrologic Evaluation of Landfill Performance [HELP ] Model (EPA, 19XX–**Will supply full ref)**to estimate the quantity and quality of leachate).

The draft assessment document states that no credit for water treatment would be given in assessing doses from drinking water for the nearby town scenarios. However, except for very small community water supplies, the water utilities would be subject to the Maximum Contaminant Levels for radionuclides and would need to treat for radionuclides if any exceedance persisted. Doses from the drinking water pathway would be limited correspondingly. At the least, this issue should be discussed in the final dose assessment document.

In many land reclamation projects, the quantity of land -applied sludge is considerably greater than what is allowable under the agricultural production scenario. Under these circumstances, the extent of soil mixing with applied sludge is generally minimal, particularly at land reclamation sites that contain little or no topsoil. The RSSS recommends that the ISCORS SSS provide scientific justification for assigning specific dilution factors to the source terms.

ISCORS SSS should describe the spectrometry analysis used to analyze the sludge and ash samples. If only gamma spectrometry was used, non-gamma emitters could have been missed. The RSSS recommends full characterization of the sludge and ash to include analysis for all radionuclides of potential concern. All radionuclides that are identified through the sludge and ash analysis should be included in the radionuclide libraries of the models.

Within the dose modeling scenarios, the radionuclide $^{99m}$Tc was not included among the radionuclides of concern, Table 2-1. This radionuclide is discharged in significant quantities from nuclear medicine operations and has been identified in sludge and/or sewage (Prichard *et al*., 1981; Ault, 989; Kennedy *et al*., 1992; Ainsworth *et al*. 1994; and Shearer *et al.*, 1995). Although $^{99m}$Tc m has a short half-life and would not contribute in nonoccupational scenarios, it could potentially contribute to direct radiation exposure of treatment plant workers.

## 3.3 Obtaining Model Parameters and Distributions, and Characterizing Uncertainty

### 3.3.1. Model Parameters and Distributions

In general, the selection of parameters and their distributions was not well described in the ISCORS SSS draft dose modeling report provided to the RSSS. In its oral presentations, the ISCORS SSS indicated that future drafts would be much improved in this regard. The RSSS supports such improvements.

The RSSS recommends that ISCORS SSS delineate which of the input parameters are unique to the sludge modeling and which have been previously examined in soil models. This would permit a reviewer to focus on the new information.

The use of one $K_d$ for each radionuclide without consideration of speciation and other factors that cause $K_d$s, solubilities, and bioavailabilities to vary across POTWs and land applications is not appropriate. The aqueous chemistry of sewage sludge (i.e., pH, $pCO_2$, dissolved solids, organic content, etc.) may vary greatly based on geographic location and treatment methodologies. These variations could lead to drastic changes in the radionuclide species present, and consequently, the model parameters associated with them (e.g., $K_d$ s, solubility constants and bioavailability factors). This could be handled by assigning these parameter values by species and application scenario or by widening the variability distributions for each radionuclide, as well as including an additional degree of uncertainty. The use of soil $K_d$ values is somewhat misleading. Depending on the sludge dewatering processes, radionuclides with substantial affinity for water in comparison to sludge solids may be largely removed during treatment. This issue was discussed in section 3.2, “Dose modeling scenarios.” We recommend that outside advice be obtained on how to treat the mobility of radionuclides in a soil-sludge mixture.

### 3.3.2. Uncertainty

The description of the sensitivity and uncertainty analysis in the current draft is inadequate for judging whether or not it is appropriate. Consequently, although the ISCORS group described future plans for conducting the sensitivity and uncertainty analyses using Monte Carlo analyses with consideration of correlations, the RSSS found that it did not have adequate information to comment in detail. The Subcommittee thus confined itself to recommending only that that all procedures and assumptions should be thoroughly documented and peer reviewed.

RESRAD was originally developed as a deterministic model. The model should be checked for difficulties relating to the probabilistic approach, e.g., singularities that could arise by dividing by a zero value for some parameter. (See the first Charge question).

A more informative uncertainty analysis would be two-dimensional, addressing both variability and uncertainty, and would examine not only parameter uncertainty but also uncertainties introduced by the selection of models and assumptions. ISCORS SSS should, at a minimum, acknowledge the difference between variability and uncertainty and provide an indication for each source, whether the distributions reflect variability, uncertainty, or a combination of both. The uncertainty analysis should recognize correlations among parameters.

ISCORS SSS should address other sources of variability and uncertainty, such as dose conversion factors (including particle size distributions).

A full description of the particular Latin Hypercube method employed should be provided, and the number(s) of realizations for the Monte Carlo runs should be justified.

In the sensitivity analysis, the statements regarding non linearity should have some technical or physical basis.

Table 7-4 of the draft report does not include the mean and median, only the 5$^{th}$ and 95$^{th}$ percentiles and the minimum and maximum. The mean and median are certainly more meaningful than the minimum and maximum values, since the minimum and maximum depend heavily on the number of iterations.

## 3.4 Issues Beyond The Charge

The RSSS understands that the ISCORS SSS is limited to assessing doses from disposition of sewage sludge *per se* and does not intend to assess doses from discharges of liquid effluents from POTWs to nearby waters. The reason for this limitation was not made clear to the RSSS by the ISCORS team; it may be a policy choice based on a presumption that the POTW's National Pollution Discharge Elimination System permit will sufficiently control radionuclides in the liquid effluent. However, the fraction of soluble radioactive material contained in the liquid effluent from the POTW may, under some site-specific conditions, contribute significantly to the total dose experienced by people living near or working at POTWs. At a minimum, this issue should be discussed in the final dose assessment document. Moreover, liquid effluent can be used for irrigation of sites to which sludge has been applied, rather than water from other sources. Therefore, concentrations of radionuclides in soils may be higher than assumed in the source term for RESRAD and there may be additional occupational routes of exposure or an additional airborne source term when effluent is used to irrigate the land application site. The ISCORS SSS should at a minimum discuss the irrigation issue and should consider including irrigation with effluent in the exposure scenarios. Assaying the liquid effluent as well as the sludge would help in understanding the partitioning of the radioactivity leaving the POTW among sewage sludge, liquid effluent, and (possibly) air emissions. Worker exposure could be monitored through personal or area dosimeters.

The RSSS understands that the ISCORS SSS is under a time constraint to provide the dose model as a tool to help interpret the results from the analysis of sludge and ash from 300 POTWs nationwide. These results will be available in a few months and it is important to assist POTWs with assessment. The EPA is considering revision of FGR-11 to reflect the ICRP Publication 72 approaches/values. However, the RSSS is uncertain when such improved numbers will be available. If they were available in time for incorporation into this Sewage Sludge report, it would be desirable to do so, both because of the improved dosimetry models used and the added ability to consider intakes by subjects of different ages. Such usage would be consistent with the approach used in FGR-13, the most current EPA guidance. If this approach can not be used in the present report, the authors should include an explanation of why it is not and explain the impact of using the older approach.

### 3.4.1. Terminology

Conventional units are used throughout the document. The RSSS recommends the use of SI units.

The RSSS recommends that the document be re-titled as “Radionuclides in Sewage Sludge and Ash: Dose Assessment Methodology.”

The RSSS recommends that the ISCORS SSS use the terms NORM and TENORM in this document, rather than using the term “enhanced NORM.” NORM can be used for exposures to naturally occurring radionuclides under undisturbed conditions and TENORM can be used for exposure to naturally occurring radionuclides whose concentrations or availability have been altered (technologically enhanced, TE) by human activities, and therefore are more likely to be eligible for control. TENORM appears to be an important component of the radionuclides found in sludge.

The term TENORM is becoming well established in the field. It is used in Part N of the Suggested State Regulations published by the Conference of Radiation Control Program Directors, has been adopted by NAS/NRC (1999), and is also used by EPA in other documents (e.g. EPA, 2000a; b; c). The definition of TENORM used in NAS/NRC (1999) is included in the glossary.

The final dose assessment report must be very careful in the use of the terms "isotopes," "radioactivity," "radionuclides," and "radioactive materials." The report should also use the correct modeling nomenclature. (See glossary.)

On page 3 of the draft dose modeling report, the term "dose-response" is used. The RSSS has used "dose-response" to mean a biological response to a particular dose. The meaning on page 3 is unclear.

### 3.4.2. Consideration of The Audience

Members of the public attending the RSSS meeting stated their concerns with the possible misunderstandings arising from the use of the dose assessment document. Suggestions were made that would allow the public to make comparisons with background radiation so that they could gain perspective on the projected doses from sewage sludge to workers or the public. The ISCORS SSS provided the latest draft of the Guidance Document to the RSSS. Section 3.3.3, "How Radiation Doses from Sewage Sludge and Ash Compare to Average Radiation Doses from All Sources," provides comparison information. It is important that the final dose assessment document produced by ISCORS SSS directs the reader to the Guidance Document for assistance in understanding the dose assessment information.

### 3.4.3. Technical Accuracy

The material in Section 2.2, "Radiological Properties of Sewage Sludge" on pages 8-10 is for the most part irrelevant. There is considerable discussion of the uses of radioactive materials, but many of the uses discussed involve sealed sources, which are unlikely to find their way into sewage sludge. Some of the statements are technically incorrect. Examples are:

a) P 9, L 9: the "isotopes" produced in reactors result from low-energy, not high-energy, neutron interactions;

b) P 9, L 12: the concentrations of radiocarbon measured in dating are usually below ambient and unlikely to contribute to sludge contamination;

c) P 10, L 6-7: strictly speaking the Department of Energy is not "licensed" for isotopes;

d) P 10, L 26: it is unit concentration being assumed, not unit quantity.

The RSSS suggests a more focused discussion that draws examples from actual contamination situations. Thus more detailed discussion of actual contamination resulting from the manufacture of smoke detectors (Am-241) or from discharge of I-131 from nuclear medicine facilities would be much more relevant than implying that radiocarbon dating or use of sealed sources in industrial gauges is somehow related to the radiological properties of sewage sludge.

### 3.4.4. Comments Related to The Appendices

Appendix A of the ISCORS SSS includes an overview of radionuclide movement in the environment. However, some nuclides are extensively discussed, while the descriptions of others are very brief. The RSSS recommends that Appendix A be revised to provide more complete information in a more consistent manner for all radionuclides of interest. In some cases, significant information may have been omitted for the sake of brevity. For instance, Appendix A states that U-235 is of secondary importance. In fact, the decay products of U-235 can contribute significantly to inhalation doses, particularly Pa-231 and Ac-227. Appendix A provides valuable information that is unlikely to be readily available to POTW owners, and it deserves careful editing.

Appendix B should be eliminated or modified to reflect the changes to be made in Chapter 4.

# APPENDIX A - GLOSSARY OF TERMS AND ACRONYMS

Absorbed Dose (D): The quotient dE by dm, where dE is the mean energy imparted by ionizing radiation to matter of mass dm. The special SI unit of absorbed dose is the gray (Gy); the conventional unit is the rad (1 rad = 0.01 Gy).

Bench marking: Part of the software verification process that involves comparing results of two or more codes against each other, or to an analytical solution. It entails the use of a standardized problem or test that serves as a basis for evaluation or comparison of software system performance. This mathematical analysis assures that the behavior of the code to be benchmarked is predictable and performs as intended.

Calibration: With reference to models, refers to the use of experimental and/or field data to constrain the value of the variables and parameters used in a model to satisfy its use for a specific application.

Committed Dose Equivalent: The total radiation dose equivalent to the total body or specified part of the body that will be accumulated over 50 years following an intake of radioactive material.

Committee Effective Dose Equivalent: The weighted sum of committed dose equivalent to specified organs and tissues, in analogy to the effective dose equivalent.

Committed Equivalent Dose (H(t)): The time integral of the equivalent dose rate in a particular tissue or organ that will be received by an individual following intake of radioactive material into the body. The integration time (t) is 50 years for the adults. For children and young persons, doses are calculated to age 70 years.

Committed Effective Dose (E(t)): The sum of the products of the committed organ or tissue equivalent doses and the appropriate organ or tissue weighting factors ($w_T$), where t is the integration time in years following the intake.

Deep-dose equivalent: Applies to external whole-body exposure and is the dose equivalent at a tissue depth of 1 cm.

Dose Coefficient: Committed tissue equivalent dose per unit intake or committed effective dose per unit intake ($Sv\ Bq^{-1}$).

Effective Dose (E): The sum of the weighted equivalent doses in all the tissues and organs of the body given by the expression: $E = w_T H_{T,R}$ where $w_T$ is the weighting factor for organ or tissue, T, and $H_{T,R}$ is the equivalent dose in tissue or organ T due to a given radiation, R.

Equivalent Dose (H): The absorbed dose averaged over a tissue or organ, $D_T$ (rather than a point) and weighted for the radiation quality, $w_R$ (radiation weighting factor) of the irradiating radiation, i.e., $H_{T,R} = D_T\ w_R$, as expressed in joules/kilogram or Sieverts.

Effective Dose Equivalent: The sum of the products of absorbed dose and appropriate factors to account for differences in biological effectiveness due to the quality of radiation and its distribution in the body of reference man. The unit of the effective dose equivalent is the rem. The method for calculating effective dose equivalent and the definition of reference man are outlined in the International Commission on Radiological Protection's Publication No. 26.

ISCORS: Interagency Steering Committee on Radiation Standards

Isotope: One of two or more atoms with the same number of protons, but a different number of neutrons, in their nuclei. Thus, carbon-12, carbon-13, and carbon-14 are isotopes of the element carbon, the numbers denoting the approximate atomic weights. Isotopes have very nearly the same chemical properties, but often different physical properties (for example, carbon-12 and -13 are stable, carbon-14 is radioactive.)

Nuclide: A general term referring to any known isotope, either stable (about 290) or unstable (about 2200), of any chemical element.

ORIA: Office of Radiation and Indoor Air, Environmental Protection Agency

Peer Review: Peer review is a general term that can greatly vary in content depending on the maturity of the problem under consideration. The peer review of a process model can involve the structural (i.e., software) or conceptual elements of the model or both. A thorough peer review of a mature process model entails Verification and Validation testing (V&V). V&V is a basic process that ensures the quality of used knowledge.

POTW: Publically Owned Treatment Works

Radioactivity: The process of undergoing spontaneous transformation of the nucleus, generally with the emission of alpha or beta particles, often accompanied by gamma rays.

Radioisotope: A radioactive isotope; i.e. an unstable isotope that undergoes spontaneous transformation, emitting radiation.

Radionuclide: A nuclide that is radioactive.

Radioactive Isotope: A radioisotope.

Sensitivity Analysis: Refers to a methodology for evaluating the sensitivity of model results to the variation of its input parameter values and physical description (e.g., boundary conditions).

TENORM: Technologically Enhanced Naturally Occurring Radioactive Material -- Technologically enhanced naturally occurring radioactive materials are any naturally occurring radioactive materials not subject to regulation under the Atomic Energy Act whose radionuclide concentrations or potential for human exposure have been increased above levels encountered in the natural state by human activities.

Tissue Weighting Factor: The relationship between the probability of stochastic effects and equivalent dose is found also to vary with the organ or tissue irradiated. It is, therefore, appropriate to define a further quantity, derived from equivalent dose, to indicate the combination of different doses to several different tissues in a way which is likely to correlate well with the total of the stochastic effects. The factor by which the equivalent dose in tissue or organ T is weighted is called the tissue weighting factor, $w_T$.

Total Effective Dose Equivalent: The sum of the deep-dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures).

Uncertainty Analysis: With reference to models, refers to the study of the uncertainty of the model outputs as a function of parameter and data uncertainties.

Model Validation: Refers to models which are comprised of structural (i.e., software) and conceptual elements. Validation entails methods to ascertain that the system built is the right one and captures all of the essential physical and chemical elements necessary to describe the problem. Controlled laboratory measurements, field experimental tests, and observations of the behavior of the natural system can all be used to test the model's realism.

Code Verification: Refers to software development. Verification is a form of code control, which involves establishing that the software is mathematically sound, accurate, and numerically stable. Verification results in the implementation of specified Software Certification goals. This is a reiterative process, comparable to the use of "blanks" and "standards" in experimental protocols. Verification implies reaching a certain level of confidence in the correctness of the software system. A common verification technique involves running the code with specified boundary conditions and parameters and comparing the results to other codes under the same conditions (e.g., bench marking).

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